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Project acronym

REALISEGRID

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D3.5.2
Final report of REALISEGRID work package 3 on transmission investments

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Abstract
The present report illustrates the key outcomes of the WP3 of REALISEGRID.

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ACRONYMS AND DEFINITIONS

AC: Alternating Current.

ATC: Available Transfer Capacity.

DC: Direct Current.

EC: European Commission.

EENS: Expected Energy Not Supplied.

ENTSO-E: European Network of Transmission System Operators for Electricity. New organisation grouping 41 European Transmission System Operators, established in late 2008 and operative from July 2009. Previous associations such as ETSO, UCTE, NORDEL, BALTSO, UKTSOA and ATSOI have been dissolved and their tasks and functions moved to the new organisation.

EU: European Union.

EU27: 27 EU Member States (from 2007).

FACTS: Flexible Alternating Current Transmission System.

HVAC: High Voltage Alternating Current.

HVDC: High Voltage Direct Current.

LMP: Locational Marginal Price.

LOLE: Loss Of Load Expectation.

LOLP: Loss Of Load Probability.

NTC: Net Transfer Capacity.

PST: Phase Shifting Transformer.

RES: Renewable Energy Source.

STUM: STUdy Model.

SW: Social Welfare.

TEN-E: Trans-European Energy Networks.

TSO: Transmission System Operator.

VOLL: Value Of Lost Load.

1 EXECUTIVE SUMMARY

In the European Union (EU), concerns related to security of energy supply, electricity market restructuring and environmental sustainability crucially drive new trends, which may significantly impact on the design and the operation of the European electricity networks.
The European power transmission grid is then on the critical path for the achievement of the EU's climate change and energy policy objectives for 2020 and beyond. The main challenge will be the power system integration of very large amounts of variable renewable energy sources (RES), while keeping acceptable standards for system reliability and progressively removing all obstacles to the creation of a unified European electricity market.
The crucial role played by the transmission system and the strategic importance of strengthening cross-border transmission networks in Europe have been remarked by different documents of the European Commission.
One of the key documents in this sense is the so-called 2010 Energy Infrastructure Package.
This EU frame is the background, within which the REALISEGRID project, and in particular the REALISEGRID Work Package 3 (WP3) 'Electricity transmission investments: a pan-European framework to assess transmission expansion benefits', has developed its activities, also to support the ongoing process at EU level. The REALISEGRID WP3 works, span over the period between end-2008 and mid-2011, have in fact contributed to the ongoing revision of the EU Trans-European Energy Networks (TEN-E) Guidelines, especially in the field of cost-benefit analysis for prioritizing pan-European transmission investments, transmission regulation, and transmission building authorisation and consensus issues. The REALISEGRID WP3 has also had different interrelations with the ENTSO-E (European Network of Transmission System Operators for Electricity), also about the challenges ahead of planning the future pan-European transmission grid.

This report presents the key findings of REALISEGRID WP3, condensing the outcomes of a wide range of activities carried out in the field of transmission planning and regulation. These constitute the so-called REALISEGRID WP3 framework: it can be defined as a set of methods and tools to assess and demonstrate the benefits provided by transmission infrastructure development to the pan-European power system and to contribute to increase transmission investments on national and multi-national levels towards the achievement of a reliable, competitive and sustainable electricity supply in the EU.
In particular, the work streams of REALISEGRID WP3 include:

- Improved system reliability and technical planning criteria (WP3.1);
- Investments signals: a quantitative approach based on cross-border capacity allocation (WP3.2);
- Implementation of a comprehensive framework to assess technical-economic and strategic benefits of transmission expansions (WP3.3);
- Coordination of investments in gas and electricity infrastructures (WP3.4);
- Application of the framework to assess technical-economic and strategic benefits of specific projects (WP3.5);
- Incentives and regulation to support transmission investments (WP3.6);
- Consensus on new transmission infrastructures (WP3.7).

This final REALISEGRID WP3 report is mainly directed to the European policy-makers and the European Commission, the national Transmission System Operators and the ENTSO-E, the national regulators and the ACER (Agency for the Cooperation of Energy Regulators) as well as to power and energy system industry and research stakeholders.

2 INTRODUCTION

2.1 Objectives of this deliverable

The European power transmission grid is on the critical path for the achievement of the European Union (EU)'s climate change and energy policy objectives for 2020 and beyond. The main challenge will be the power system integration of very large amounts of variable renewable energy sources (RES), while keeping acceptable standards for system reliability and progressively removing all obstacles to the creation of a unified European electricity market.
The key role played by the transmission system and the strategic importance of strengthening cross-border transmission networks in Europe have been remarked by different documents of the European Commission [1][2][3][4][11].
Concerning the development of new transmission infrastructures, the European Transmission System Operators (TSOs) have substantially kept a national scope so far.
However, this approach proved unable to provide a pan-European view and take into account the cross-border needs originated by complementary generation sources located in different European places. In the recent years, the European Commission issued some documents and new regulations to fill this gap.
One of the key documents in this sense is the so-called 2010 Energy Infrastructure Package [3].
This EU frame is the background, in which the REALISEGRID project, and in particular the REALISEGRID Work Package 3 (WP3) 'Electricity transmission investments: a pan-European framework to assess transmission expansion benefits', has developed its activities, also to support the ongoing process at EU level. The REALISEGRID WP3 works, span over the period between end-2008 and mid-2011, have in fact contributed to the ongoing revision of the EU Trans-European Energy Networks (TEN-E) Guidelines [2][3], especially in the field of cost-benefit analysis for prioritizing pan-European transmission investments, transmission regulation, and transmission building authorisation and consensus issues. On the latter point, an Interim Report, containing different proposals for streamlining planning and approval procedures of transmission infrastructures in Europe, has been produced, upon expressed request by the European Commission.

The REALISEGRID WP3 has also had different interrelations with the ENTSO-E (European Network of Transmission System Operators for Electricity) [5], also about the challenges ahead of planning the future pan-European transmission grid [20].

This report presents the key findings of REALISEGRID WP3, condensing the outcomes of a wide range of activities carried out in the field of transmission planning and regulation. These constitute the so-called REALISEGRID WP3 framework: it can be defined as a set of methods and tools to assess and demonstrate the benefits provided by transmission infrastructure development to the pan-European power system and to contribute to increase transmission investments on national and multi-national levels towards the achievement of a reliable, competitive and sustainable electricity supply in the EU.
In particular, the work streams of REALISEGRID WP3 include:

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- Application of the framework to assess technical-economic and strategic benefits of specific projects (WP3.5);

- Incentives and regulation to support transmission investments (WP3.6);
- Consensus on new transmission infrastructures (WP3.7).

2.2 Expected outcome

In this report, the content is structured as in the following.
Chapter 3 first introduces the background on the ongoing developments related to the European power infrastructure policy. Then, after recalling the basic elements of transmission planning and current issues, it sets the scene for presenting the activities carried out within the REALISEGRID WP3 in the field of transmission planning, investments and regulation. The outcomes of these works form the REALISEGRID WP3 framework.
Chapter 4 provides the main findings of the REALISEGRID WP3 works on the technical aspects related to transmission expansion planning in Europe. These include: the review of transmission planning methods and rules for the grid connection of large wind plants; the extension of transmission planning criteria by the development of a methodology handling uncertainties; the set-up of a market integrated approach to transmission expansion in the European context, the combination of the related tools and the application on a European test-bed; the development of a methodology and related tool for multi-criteria cost-benefit analysis to transmission planning in Europe, and the application on a portion of continental Europe system; the build-up of a methodology and related tool for a coordinated assessment of investments in electricity and gas infrastructures.
Chapter 5 provides the main findings of the REALISEGRID WP3 works on the regulatory aspects related to transmission expansion planning in Europe. These include: the remuneration and incentivisation of transmission investments; the authorisation procedures and the consensus issues. Finally, policy recommendations are drawn.

2.3 Approach

The present REALISEGRID Deliverable D3.5.2 highlights the key outcomes of REALISEGRID WP3 activities. These have been fully described in the following REALISEGRID Deliverables (which the interested reader can refer to for all details and results):

- D3.1.1 - "Review of existing methods for transmission planning and for grid connection of wind power plants" [16]
- D3.1.2 - "Report on extension and harmonisation of transmission planning criteria" [21]

- D3.2.1 - "Coordination Mechanisms, Tools and Load-Flow Issues of Cross-Border Transactions" [22]
- D3.2.2 - "Price, Cost and Financial Aspects of Network Extension in the European Context" [23]
- D3.2.3 - "Case study: Model-Based Transmission Investment Signals in Central Western and Central Eastern Europe" [24]

- D3.3.1 - "Possible criteria to assess technical-economic and strategic benefits of specific transmission projects" [12]
- D3.3.2 - "Review of costs of transmission infrastructures, including cross border connections" [15]

- D3.3.3 - “Tool for the assessment of benefits given by the expansion of transmission infrastructures” [17]

- D3.4.2 - “Tool for a coordinated assessment of investments in electricity and gas infrastructures” [25]
- D3.4.1 - “Report on identification of weaknesses in electricity and gas infrastructures by a probabilistic coupled model for electricity and gas infrastructures” [26]

- D3.5.1 - “Application of the REALISEGRID framework to assess technical-economic and strategic benefits of specific transmission projects” [27]

- D3.6.2 - “Incentive schemes and regulation framework for transmission development in Europe” [28]
- D3.6.3 - “Transmission Grid Investments for an Efficient Integration of Renewable Energy Sources” [29]
- D3.6.1 - “Evaluation of electricity infrastructure development, investment needs, regulation and policy recommendations” [30]

- Interim Report - “Preliminary results on streamlining planning and approval procedures of electricity transmission infrastructures” [31]
- D3.7.1 - “Review of existing transmission planning and approval procedures and coordination of infrastructure developments between TSOs” [32]
- D3.7.2 - “Improving consensus on new transmission infrastructures by a thorough presentation of the benefits given by priority projects” [33]

In addition, the REALISEGRID WP3 work takes stock of the outcomes of REALISEGRID WP1, focused on the developments of innovative transmission technologies, and of REALISEGRID WP2, building up the pan-European long term energy scenarios (up to 2030). In particular, the works of REALISEGRID WP1 [13][34] and of REALISEGRID WP2 [8][9] have been taken into due account.

3 BACKGROUND

3.1 Overview of the European context

In the European Union (EU), concerns related to security of energy supply, electricity market restructuring and environmental sustainability crucially drive new trends, which may significantly impact on the design and the operation of the European electricity networks. The European transmission grid is then on the critical path for the achievement of the EU's energy and climate change policy targets for 2020 and beyond, that aim at promoting a better integration of a steadily increasing amount of RES, while keeping acceptable standards for the security of supply and progressively removing all obstacles to the future creation of a unified European energy market.

The central role of the transmission grid within the EU energy policy calls for a truly pan-European approach to the planning and operation of these infrastructures, especially for those ones having a significant cross-border impact. The strategic importance of strengthening cross-border transmission networks in Europe has been remarked by different documents of the European Commission [1][2][3][4][11].

Concerning the development of new transmission infrastructures, the European Transmission System Operators (TSOs) have substantially kept a national scope so far.

However, this approach proved unable to provide a pan-European view and take into account the cross-border needs originated by complementary generation sources located in different European places. To fill this gap, the European Commission issued in 2006 the Trans-European Energy Networks (TEN-E) Guidelines document [2], featuring a list of infrastructures recognized as priority projects of European interest. However, after few years, this approach has shown evident limitations in that this list, actually collected from the different TSOs in a bottom-up way, did not really highlight the true pan-European priorities. Also, notwithstanding recent improvements in unlocking some TEN-E priority projects of European interest, due e.g. to the intervention of a European Coordinator, the situation for the completion of such projects remains critical. In fact, out of 32 TEN-E priority projects of European interest, as of March 2010, only a small quota of them, 16%, has been completed, and 29% of them refers to projects under construction, while the relevant share of 55% still lies in the authorization path and/or in the study or reconsideration phase [18].

In this frame, in order to overcome this critical situation, the European Commission issued two Communications in Nov. 2010.

The first one [4] defines energy strategy priorities in Europe towards 2020 targets and calls for a step change in the way energy infrastructures and networks in Europe are planned, constructed and operated.

The second one [3] (so-called 2010 Energy Infrastructure Package), more specifically, sets the creation of a pan-European methodological approach in prioritizing the projects of European interest as a key measure towards EU targets for 2020 and beyond. In this direction, a crucial role is played by ENTSO-E, the association gathering the European TSOs, which will have to progressively implement the necessary transmission development evolution steps to address the EU requirements. A preliminary, important contribution to this process was given by the first (pilot) ENTSO-E's Ten-Year Network Development Plan (TYNDP) 2010-2020 [6], issued in 2010, to be updated every two years. Although the 2010 TYNDP was still obtained by means of a bottom-up data collection from the national TSOs, this methodology will be gradually changed in favour of a new pan-European approach.

In the Energy Infrastructure Package [3], the European Commission proposes the following steps:

- Identification of the energy infrastructures leading towards a pan-European smart network (so-called "supergrid").

- Focus on a limited number of European 2020 priorities, where EU action can play a major role, to meet the long-term objectives.
- Selection of concrete projects necessary to implement the European priorities in a flexible manner so as to respond to changing market conditions and technology development.
- Support of the implementation of European priority projects through new approaches and tools, aiming at fostering regional cooperation, streamlining permitting procedures, improving methods and information for decision makers and citizens as well as applying innovative financial instruments.

To ensure timely integration of renewable generation capacities in Northern and Southern Europe and foster further market integration, in [3] four crucial priority corridors of the European power system, that will have to be more urgently developed and reinforced, are identified. These are (see also Fig 1):

a. Offshore grid in the North Seas and connection to Northern and Central Europe
b. Completion of the BEMIP (Baltic Energy Market Interconnection Plan)
c. Interconnections in South Western Europe
d. Connections in Central Eastern and South Eastern Europe

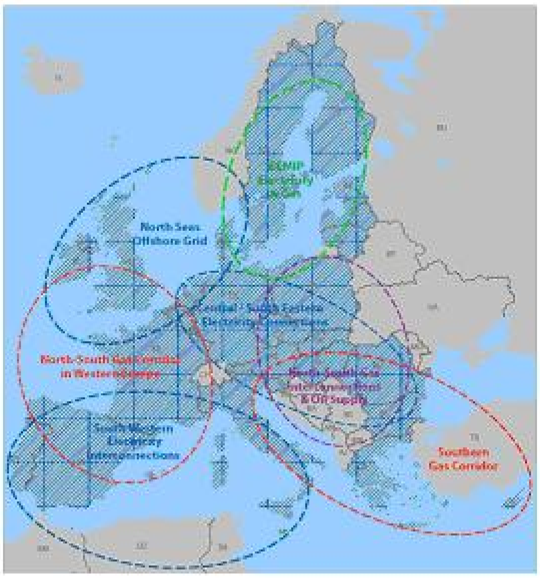

Fig 1 - Priority corridors in Europe (source: [3])

It has to be remarked that the realisation of a potential pan-European supergrid is a complex process that can only be considered in a long-term perspective (after 2020), as there are still several techno-economic, technological, regulatory, market and socio-environmental issues that will have to be properly handled and solved over the years. Towards this goal, considering the needed progressive re-engineering process and the relevant paradigm shift with respect to the traditional approach to transmission system development and operation adopted so far in Europe, different stages for an incremental evolution from the current European grid are to be foreseen [19]. In this sense, a modular development over the years, especially after 2030, is an essential requisite for a successful implementation of such ambitious plan, as recalled by the European Commission [3] and by ENTSO-E [6][20].

In conclusion, within the European framework, as summarized above, there is then a need for a pan-European methodological approach to the planning of new assets, especially those having a significant cross-border impact. Such an approach entails harmonizing the different national regulations, fostering the achievement of a coherent policy promoting the most urgent reinforcements and the most viable techno-economical solutions, while overcoming possible local opposition by means of transparent information to the public able to provide clear figures of costs and benefits. On these topics REALISEGRID WP3 outcomes, whose key findings are described in Chapter 4 and Chapter 5, have been of useful support to the European Commission in the preparation of the Energy Infrastructure Package.

3.2 The transmission expansion planning process

The transmission expansion planning process is a complex task in which the network planners need to handle several uncertainties and consider different risk situations. Some important criticalities make this task at the same time crucial and very delicate [6][12][16].

First, changes in future system conditions significantly affect benefits of transmission expansion. For this reason, transmission planners need to fully capture all impacts a project may have, examining then a wide range of possible system conditions.

Furthermore, it takes much longer to get a new transmission line approved and built (at least 5 years and in most cases more) than similar procedures for new generation facilities (e.g. gas fired power plants in only 2-3 years). Therefore, the development of the transmission grid always lags behind the development of generation. This can only be taken into account by using different situations and scenarios. Methodologies and criteria developed by TSOs focus on risk assessment and mitigation, building both on their past experience and scenarios to envisage future situations. They assess the resilience of the system in whatever situation it may have to face: high/low load, generation dispatch patterns, adverse climatic conditions (defined in the scenario phase), and/or contingencies, for example [6][7].

The transmission planning process with its basic scheme and stages is depicted in Fig 2 [12].

The first stage of planning concerns the power system projection (scenarios) over the analysed timeframe in terms of those elements which may impact on the transmission grid evolution over the years of observation. Such elements regard the projected trends of load demand, import/export and production (phasing in and out of respectively new and old generation), which also depend on economic, market, policy and regulatory drivers (like for example the EU 2020 targets). The development of system scenarios, related to the targeted time horizon, provides then the boundary conditions for planning the transmission expansion. In fact, within the frame of the developed scenarios for the specific area under study, transmission planners need to check whether their related network in unchanged conditions (without any expansion, 'doing nothing' alternative) is still reliable, that is secure and adequate. This analysis is carried out by applying static and dynamic security criteria, which in general are referred to as (n-1)[1] criterion. In some specific cases, more severe contingencies than those ones applied by the (n-1) criterion can be taken into account by transmission planners, like for example situations of double contingency (when applying (n-2) security criterion), multiple contingencies, loss of busbar(s) [6]. Whereas these planning criteria are

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[1] The (n-1) security criterion is a transmission planning (and operation) rule: it consists in verifying that, in presence of a single contingency (that is, outage of a single network component like line/transformer/generator/controlling device/cable or busbar in some cases), parameters like power flows, voltage and current amplitudes regarding the different network elements are all within the respective operational security limits (maximum acceptable values).

met, then the network can be considered secure and does not generally need an expansion to accommodate the evolution scenarios. On the other side, whereas the security (reliability) analysis regarding the unchanged network within the developed scenarios is not satisfied, a transmission reinforcement action must be taken into account by the planners. This stage aims then to specifically solve issue(s) and address need(s) in the system: these planners' targets might be for example represented by achieving a transmission capacity enhancement or reaching a desired level of voltage amplitude(s). To address a specific problem in the system, different reinforcement solutions may be available, ranging from upgrading/uprating the existing assets to building new ones. The available options span from conventional technologies such as HVAC (High Voltage Alternating Current) overhead lines, transformers, cables to more innovative devices like HVDC (High Voltage Direct Current) and FACTS (Flexible Alternating Current Transmission System); also a combination of different solutions might be an option [13].

After identifying a first, broad group of possible reinforcement solutions which address a specific problem in the system, the task of transmission planners is to carry out a cost-benefit analysis of the different options: the aim is in fact to compare and rank them to select the most feasible one(s). The cost-benefit analysis of the expansion alternatives consists in a techno-economic assessment of each of them: all the benefits provided by every option need to be carefully and quantitatively evaluated against their respective investment and operating costs. This analysis nowadays takes more frequently account of environmental and social issues as well, considering the crucial role that such aspects play towards the expansion of a transmission system. Until a recent past, a socio-environmental assessment was a further (even optional) stage in the transmission planning process subsequent to the techno-economic assessment towards the final ranking of the different expansion options. Indeed, environmental constraints and social opposition have often obliged the transmission planners to reshape the rank of the investigated alternatives. For a modern transmission planning, it is nowadays of paramount importance to quantitatively evaluate socio-environmental aspects and consider them for a more complete and systematic cost-benefit analysis.

Subsequent step is the submission of the selected transmission expansion plan(s) related to top-ranked option(s) to the respective decision-makers (such as the competent ministries and/or regulatory authorities) for their approval. This stage is then deepened by the application of the authorization procedures path at all levels (national, regional, local) as required by the respective law. Without the completion of this authorization process, the final stage of transmission expansion construction and operation start cannot begin.

In Fig 2 the part in red depicts the traditional approach to cost-benefit analysis, while the part in green displays a more extended approach, which also includes social and environmental aspects: the latter one is the approach proposed by REALISEGRID project [12].

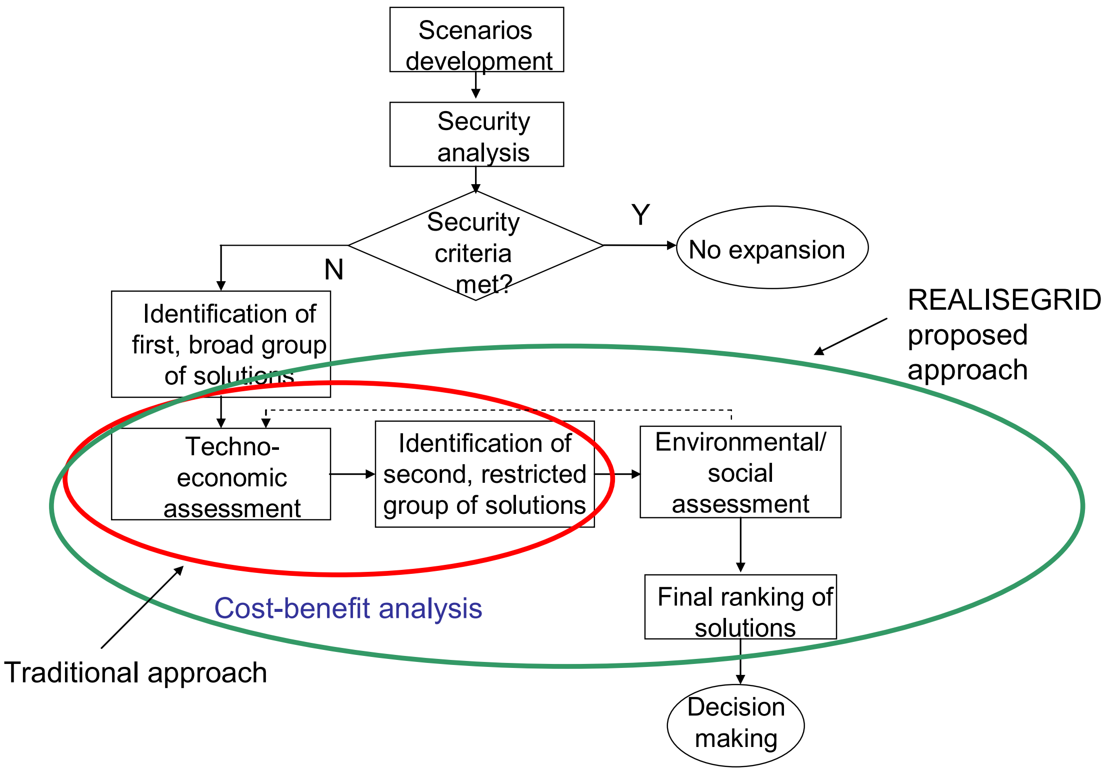

Fig 2 - Basic scheme of the transmission planning process

3.3 The REALISEGRID WP3 framework

The REALISEGRID WP3 'Electricity transmission investments: a pan-European framework to assess transmission expansion benefits' is devoted to implement a framework. This can be defined as a set of methods and tools to facilitate harmonisation of pan-European approaches to power transmission development and to evaluate benefits of transmission investments. Final goal is to contribute to increase transmission investments on national and multi-national levels towards the achievement of a reliable, competitive and sustainable electricity supply in the EU.

The different REALISEGRID WP3 work streams can be classified as in the following (see also Fig 3).

- ***Planning practice***
  WP3.1 aims at analyzing current transmission planning practice and developing a robust **set of criteria for improved transmission planning** in presence of a **large penetration of RES-E generation**.

- ***Modeling tools***
  WP3.2 evaluates **bottlenecks** and **investment needs** in cross-border capacities in the European electricity markets.

WP3.3 sets up a **methodology** and a supporting tool to carry out **multi-criteria cost-benefit analysis** supporting the development of trans-European transmission infrastructure.

WP3.4 aims at creating a tool to support **coordinated investment in electricity and gas infrastructure**.

- ***Testing bed***

WP3.5 focuses on the validation of the cost-benefit methodology set up in WP3.3 on a **realistic case concerning the TEN-E priority axis EL2**.

- ***Regulation***

WP3.6 aims at analyzing the impact of **regulation** and **incentive mechanisms on transmission investment**.

WP3.7 focuses on a benefit-based approach to **improve consensus** on new infrastructures.

The following Chapter 4 focuses on main findings of technical-economic aspects of transmission planning (WP3.1 to WP3.5), while Chapter 5 describes the main outcomes of regulatory issues related to transmission planning (WP3.6-WP3.7).

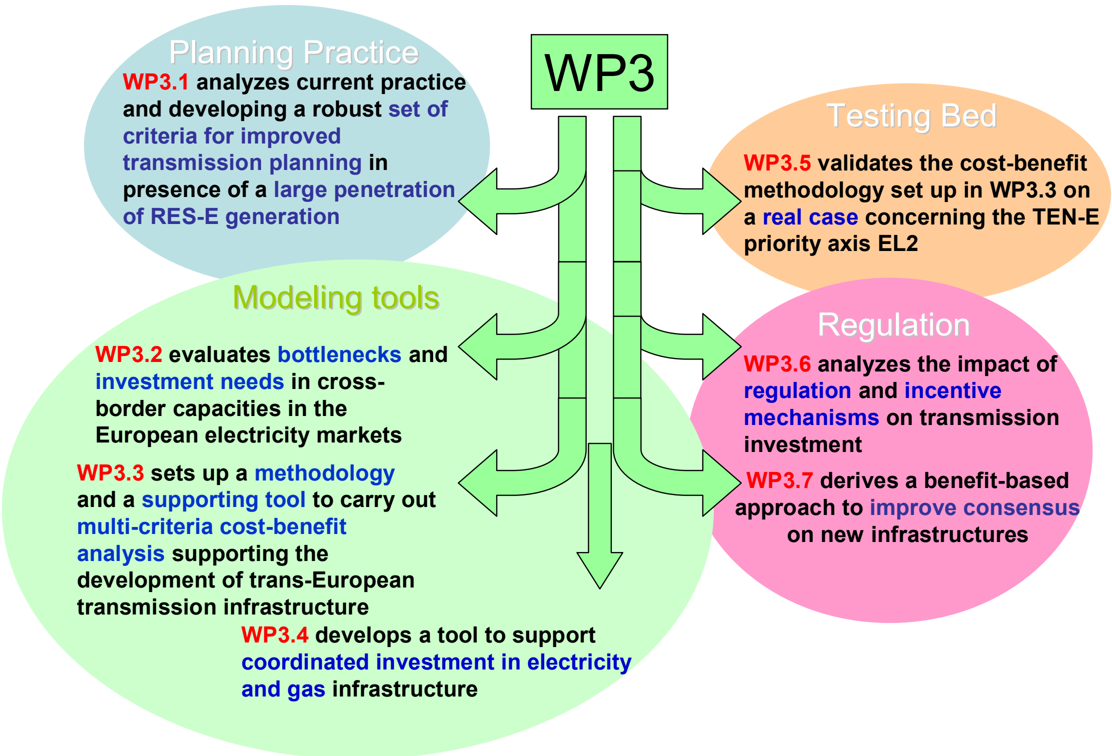

Fig 3 - Main streams of REALISEGRID WP3 activities

4 MAIN FINDINGS ON TRANSMISSION PLANNING

This Chapter presents the main outcomes of the REALISEGRID WP3 works on the technical aspects related to transmission expansion planning in Europe. These include: the review of transmission planning methods and rules for the grid connection of large wind plants; the extension of transmission planning criteria by the development of a methodology handling uncertainties and its application; the set-up of a market integrated approach to transmission expansion in the European context, the combination of the related tools and the application on a European test-bed; the development of a methodology and related tool for multi-criteria cost-benefit analysis to transmission planning in Europe, and the application on a portion of continental Europe system; the build-up of a methodology and related tool for a coordinated assessment of investments in electricity and gas infrastructures.

4.1 WP3.1 – Wind integration and transmission planning in Europe

4.1.1 Practices for wind grid connection/integration and transmission planning

The present activity has analysed different methods adopted for grid connection/integration of large wind power plants and for transmission planning in Europe.

Focus has been firstly on the technical requirements posed on the wind turbines in order to be connected to the power transmission grid. In the latest years, many TSOs have been changing the grid connection rules for wind power plants. The current trend in Europe is that the amount and severity of these requirements is generally increasing with the respective wind penetration level.

The most important specifications for wind farm connection to the transmission grid, introduced over the last years and generally contained in the Grid Codes of the TSOs, refer to: voltage and frequency operating limits, active and reactive power control, and fault-ride through capability. These key requirements have been assessed through a systematic and easy-to-visualize comparison for many European countries [16]. Nowadays, there is an ongoing effort by ENTSO-E [5] and ACER [36] to harmonise the different European grid connection requirements.

An assessment of the wind connection charging methods and policies in all 27 EU countries has been then conducted. Grid connection procedures are accompanied by connection costs that may include all or a part of the needed transmission expansion costs. This investigation has highlighted extremely varying charging methods in the EU, ranging from shallow to deep approach [16].

Then, there has been a broad assessment of the network planning practices in Europe, with particular attention paid to the planning issues for wind integration.

The transmission network planning is a very complex process and recent trends and challenges make it even more complicate.

In the past, before the electricity market liberalisation, the transmission network was expanded with the aim to minimise both generation and transmission costs, while meeting static and dynamic technical constraints, to ensure a secure and economically efficient operation. Today, the TSOs aim at two main objectives when planning the development of the transmission grid: maximising system reliability and security of supply and fostering market, to allow an efficient use of generation, thereby minimising the total costs. In a competitive market, the TSO plans the expansion of its network by minimising transmission cost (investment and operation) and pursuing maximum social welfare, while meeting static and dynamic technical constraints to ensure a secure and economically efficient operation [16].

Resolving then the trade-off between minimum transmission investment cost versus maximum social welfare is a complicated task and results in different objective functions for different TSOs. A major challenge for the TSO planning departments is to reconcile short-term market-based needs

with longer-term policy-based and security of supply needs. Transmission investments certainly help also to mitigate the possible exercise of market power, which generally leads to socio-economic losses.
Tab 1 provides a first comparison of key features of the planning practices in some European countries. Among these elements, features like the timeframe for network planning, the utilisation of deterministic and probabilistic planning criteria, also with consideration of market issues, are quantitatively and qualitatively compared [16].

Country / Area	Time horizon for adequacy and planning studies	Deterministic (D) and probabilistic (P) network planning criteria									Consideration of market issues in network planning					
		D			D with P items			P			Low			High		
NORDEL	5-10 years	■	■	■	■	■	■				■	■	■	■		
France	7-20 years	■	■	■	■	■					■	■				
Great Britain	7 years	■	■	■							■	■	■			
Ireland	5-10 years (15-20 years time frame for a limited set of studies)	■	■	■	■						■	■				
Italy	5-10 years	■	■	■	■						■	■				
Spain	10 years	■	■	■	■						■	■	■			
The Netherlands	7 years (21 years in the strategic Vision2030 document)	■	■	■							■	■				

Tab 1 - Comparison of planning practices in some European countries/areas (2008) [16]

What emerges clearly by the screening of many Grid Codes and planning documents is that the network planning and the generation connection processes are two separate yet intrinsically interlinked procedures. This particularly applies to wind electricity, which has not simply to be connected to the closest busbar of the grid but, most importantly, has to be effectively integrated into the system through targeted network development and optimization actions [16].
An overview of the deterministic and probabilistic analyses carried out by the TSOs has been then executed. The results show how, notwithstanding stochastic elements are more and more pervading the current power systems, probabilistic approaches - which would help in better capturing the evolution of the system to take into account e.g. the stochastic nature of wind production - are not yet fully implemented; in some cases, they mainly aim to complement deterministic analyses, upon which the planning decisions are primarily made (i.e. the probabilistic analyses are not integrated with the overall planning process).
Considering the ongoing and forecasted offshore wind deployment in North Europe, there exist several, dedicated plans for multinational offshore grids[2]. Their contribution to increased security of supply, their function for the aggregation and dispatch of power from offshore wind farms (by e.g. allowing hydro power import from Norway to the British and the continental Europe system), and

[2] Among them, there is the North Seas Countries Offshore Grid Initiative (NSCOGI), jointly launched by ten nations (Belgium, Denmark, France, Germany, Ireland, Luxembourg, Netherlands, Norway, Sweden, United Kingdom) in Dec. 2009 with the main objective to coordinate the offshore wind and infrastructure developments in the North Seas.

their role as exchange and trade facilitator between power systems are among the recognised benefits of such grids. The development of offshore wind power will increase the need for grid reinforcements of the existing onshore grid. In some countries (e.g. Germany [10]), bottlenecks already exist and/or are expected to increase in the event of significant wind capacity expansion in the North Sea [6][16].

As recommendations, transmission planning should be focused on two directions: a better coordination between national TSOs and an improvement of the transmission planning methods. The main keys to obtaining a reliable and effective European grid are integrated strategic planning and cross-border coordination. To this purpose Grid Codes, policies and regulations should be harmonised for facilitating trans-national projects. Existing transmission planning methods will have to capture more combinations of load, (renewable) generation and international exchange for gaining a more comprehensive system view under a variety of possible scenarios. Probabilistic approaches to deal with such uncertainties should be more and more used.
An aspect not yet appearing among the priority concerns of most of the network planners is the intertwined development of transmission and distribution networks, due to the deployment of distributed generation and SmartGrids concepts. In general, TSOs still have to devise strategies to address in a systemic way the issues deriving from future developments towards SmartGrids. These aspects should not be neglected in the near future [16].

4.1.2 Extension and harmonization of transmission planning criteria

The focus of this activity has been on improving the security analysis used for network expansion planning by proposing new, risk-based criteria for the identification of critical grid elements. The liberalization of the electricity sector together with the current and foreseen large penetration of variable renewable energy sources increase the uncertainties of power flows in the system. Hence, planning based on snapshot analysis is no longer sufficient and a trend towards probabilistic planning methods can be noticed. A statistical method for bottleneck evaluation to be used in transmission expansion planning is presented in this report. The method includes a round-the-year approach that is adequate for interconnected power systems that have a high penetration of wind power. Market simulations are combined with detailed load flow calculations for getting a complete picture of the congestions in the transmission grid, while considering the chronological aspect and the (auto)correlation properties of load and wind-speed time series. In order to examine bottlenecks a ranking method was developed according to a risk-based severity index.
The testing validation of the method has been performed on a modified New England system that includes wind power plants, using one year of load and wind data. By comparing the results of the snapshot method with the proposed round-the-year method for one area, it is shown that the new method gives more accurate results, identifying bottlenecks that the snapshot method misses. A reliable bottleneck ranking is made, based on the calculation of the risk of overload. In addition, an analysis for all the six tie-lines of the New England system has been made via the proposed method. The top three bottlenecks have been identified. The market simulation results regarding the energy exchanges between the three areas justify the presence of congestion in these transmission corridors. Detailed security analysis results indicate which are the affected physical branches in the system. The relationship between the risks of overload of different transmission branches versus the exploitation of renewables (with a focus on wind power) can be also studied with the proposed method. An example has been presented and the New England test system has been used again. Three wind penetration scenarios have been chosen. The bottleneck ranking method has been used

for each scenario and the results have been compared. The focus is on the tie-lines. It can be noticed that by increasing the installed wind power the severity of congestion also increases.

This activity has also made suggestions for the harmonization of the planning process that should accompany the proposed method. The need to coordinate national and European transmission development studies is emphasized. It is important for the various TSOs to agree on common parameters such as bottleneck ranking weights and overload thresholds to be used in the new method. The quality of input data for scenario development is also underlined as it has a direct influence on the validity of the results.

4.2 WP3.2 - An integrated market approach to transmission network expansion in the European context

In Europe, the markets reform process developed over the years (starting from mid-90ies) through different EU and national legislation instruments, above all the three EU liberalisation Directives [35]. With the restructuring of the electricity industry, vertically integrated structures were broken up and the segments of generation and supply were opened for competition, while transmission and distribution remained regulated.

In this framework, in technical practice and scientific literature there exist different approaches to transmission network expansion in regulated and liberalized systems (some of them are described and referred to in [12][22]). Among them, there is a welfare maximizing or economic approach, based on nodal pricing for network calculations and market solving.

Another option to transmission network expansion is provided by an engineering focused or security approach, which emphasizes the aspects of reliability and security of supply. Thereby, TSOs have to use reliable methods and to foresee the weak points and bottlenecks in the grid and react in time to secure supply and safe grid operations. These needs imply certain medium- and long-term grid expansions which are urgently required to cope with the future challenges in the energy industry. The security approach, applying the (n-1) criterion, considers the feasibility of certain extension opportunities including technology choice (e.g. cable vs. overhead line) and technical constraints resulting from security of supply.

Combining the two different approaches above mentioned, while also including a market view on cross-border investment projects, a new, integrated methodology, tailored to the European situation, has been developed [23].

The economic view is taken into account by the implementation of the modelling tool ELMOD[3], whose main features are:

- Europe-wide electricity market model
- Nodal pricing approach to measure the economic scarcity of transmission capacity
- Total social welfare maximization

However, the approach by ELMOD is subject to some limitations, due to a simplified power system representation and significant assumptions needed to deal with nodal data.

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[3] The tool ELMOD (developed by the Chair of Energy Economics and Public Sector Management at the Technical University Dresden) implements a model of the European electricity market. It can be classified as an optimization model whose objective function is the maximization of the social welfare. It allows a wide array of different analyses, such as network management and extension simulations, unit commitment and generation expansion analyses, and market simulations [22].

The security view is taken into account by the implementation of the tool Integral[4], whose main features are:

- Detailed analysis of system reliability incorporating (n-1) calculations
- Identification of critical network situations to measure the technical scarcity of transmission capacity

This approach is also subject to some limitations, because the impact of the bidding in the electricity market is not considered.

This last aspect (market view) is taken into account by the implementation of a third tool, eAuctionyzer[5], whose main features are:

- Monte Carlo approach based on the bidding behaviour of market participants
- Ability to calculate market potential for a new cross-border capacity expansion
- Full assessment of the volatility of price

The limitation of this approach is due to the fact that the market players focus on short-term profits and have limited insight into the technical requirements.

The integrated market approach proposed embraces all three views accounting for their individual limitations

- The calculations by ELMOD and Integral are functional to highlight investment packages (i.e. bundles of several investment projects that should be carried out together)
- The Monte Carlo simulations by eAuctionyzer are then used in order to screen the investment packages proposed by the two former tools from a market perspective

For the ELMOD simulations, twelve time slices are chosen which cover both extreme and average load and generation conditions. Summing over all time slices, the ELMOD calculations yield the power price forecast which is used as a calibration for the further simulations. As inputs, the assessment of generation and consumption for each time slice is a preliminary requirement. The results are then aggregated for each market area.

For the following stage, a full load flow calculation with the tool Integral is carried out to ensure safe grid operation and the security of the system represented by the (n-1) criterion. For this purpose, the above described patterns of generation and consumption are used again as well as an accurate representation of the network for one selected characteristic time slice (see [23][24] for all details). Having an estimation of the power prices as well as the respective network constraints, the market simulation can be conducted. The market simulation reflects the currently applied practice of an explicit or implicit coordinated allocation. Specifically, the approach for this methodology has been based on data from the explicit auctioning of the Central East Europe (CEE) region as for this region extensive auction data are available. The results of the allocation are accepted volumes and market clearing prices, network flows caused by the commercial exchanges between the different countries, the social welfare of the auction and the total auction income for the participating transmission system operators. The knowledge of these data leads to clear and transparent investment signals such as network flows and shadow prices, which allows assessing the investment project packages [23].

An application of this market integrated approach to transmission expansion planning has been performed on a portion of the central European system at 2030 [24].

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4 The power system software tool Integral is used by the Austrian TSO, APG, for grid operation as well as for grid planning. It combines various processes under an optical user interface [22].

5 eAuctionyzer is a tool built on for traders dealing with load flow based capacity auctions [24][37].

Fig 4 and Fig 5 show two investment packages highlighted in ELMOD/Integral on the two adopted 2030 scenarios (optimistic and pessimistic).

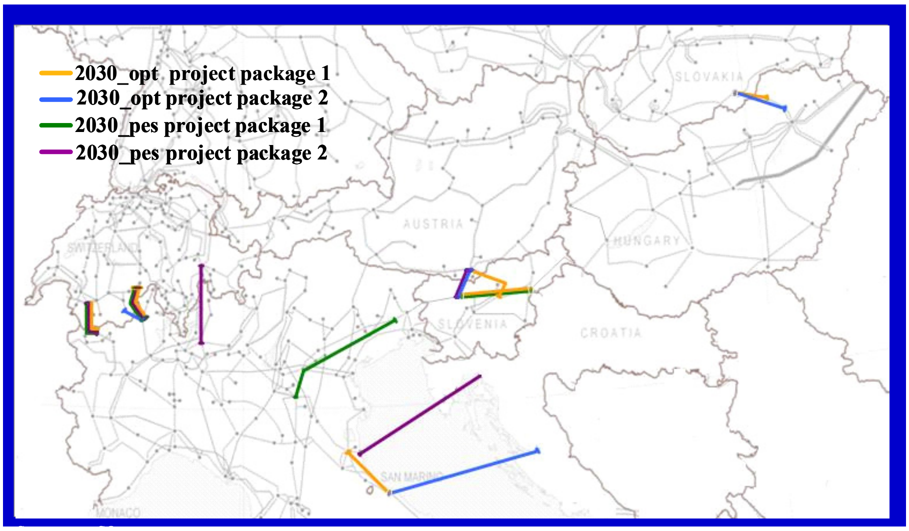

Fig 4 - Investments packages between Italy and neighbouring countries ([24])

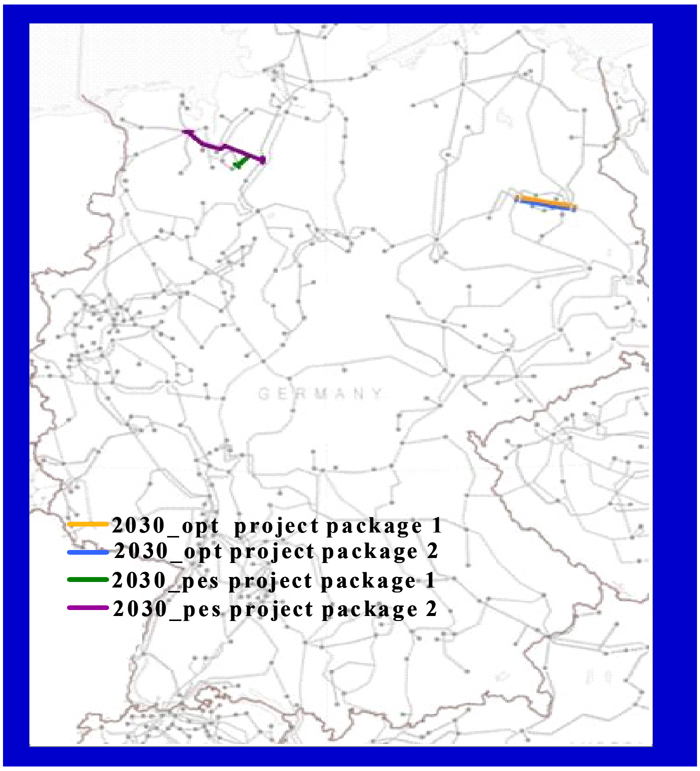

Fig 5 - Investments packages in Germany ([24])

Then, based on the screening carried out by eAuctionyzer, the investment relevant to package 1 results to be preferred over the one of package 2. All details of this methodology application are reported in [24].

The tested methodology results to be robust and feasible. Naturally, the final results are very scenario-dependent (i.e. dependent a lot on the input data).

The Austrian TSO, APG, has already decided to implement some fundamental ideas of the proposed method for its decision-making process.

4.3 WP3.3 and WP3.5 - A multi-criteria approach to cost-benefit analysis for transmission network expansion in Europe

In this section, a brief overview of the new REALISEGRID multi-criteria approach to cost-benefit analysis is provided, with focus on the following aspects:

- Cost-benefit methodology [12]
- Screening of benefits [12][27]
- Screening of relevant costs [15]
- Features of tool for benefit evaluation [17]
- Test-bed application in the European system [27]

4.3.1 Methodology

Transmission planning is inherently a multidimensional decision process (technology cost, economic gain, emission reduction, easy-to-get consensus etc.).
Each national TSO has its own criterion to co-evaluate all the weights with the investment costs.
However, at European level a common criterion is needed to provide an objective procedure to decide which (cross-border) investment is worth to be funded by EU.
Aim of a full-fledged cost-benefit analysis [12] is to provide a criterion to co-evaluate the effect of each benefit weighing them together to provide one single ranking value. This value represents the degree of optimality of a single expansion project. In this way, different alternatives can be compared, the highest ranked being the most suitable to be financed and realized.
In other words, creating a merit order (ranking) between alternative reinforcements means mapping the different evaluations of the benefits of each single infrastructure into one mono-dimensional space. According to the theory of multi-criteria analysis, a weighed sum is performed by adding up the value of each benefit and subtracting investment costs to this amount. In order to take into account the long lifetime horizon of the entire investment cycle (authorization time, building time, amortization time following the entrance in service of the new infrastructure), the Net Present Value (NPV) algorithm has to be applied, see Fig 6.

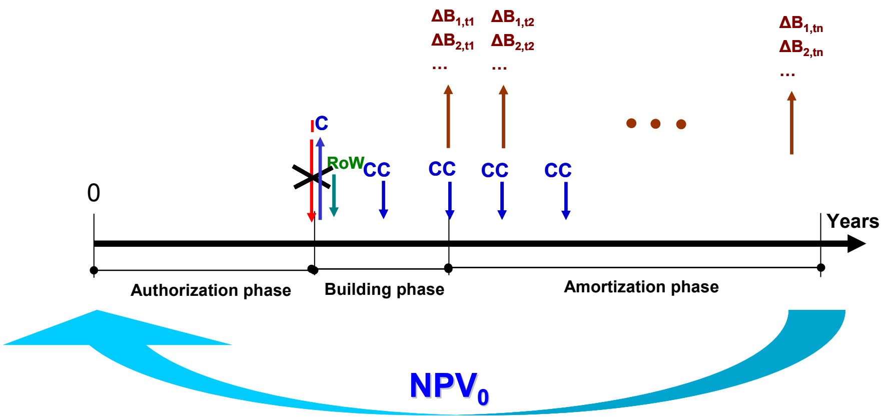

Fig 6 - Phases of transmission investment process

The weights associated to each single benefit mimic the importance associated to each of them: this operation, even if not codified, is already performed by each TSO. The aim of the REALISEGRID

approach has also consisted in widening as far as possible the list of benefits and bringing it to a structured state, so that a general, documented and objective approach is established and brought to the attention of ENTSO-E as well as of the single TSOs.
The use of NPV and the application of the above described multi-criteria methodology for transmission expansion cost-benefit analysis can be also an effective instrument to evaluate the **cost of inaction** due to a delay in one or more stages of the transmission planning process. Then, in case of lengthy or prolonged authorization path, the change (loss) in the ΔNPV, calculated for an equal interval of years, can be a measure of the cost that a postponement of the realization of a transmission option has caused to the society [12].

4.3.2 Definitions of benefit

Within the cost-benefit analysis, it is crucial to quantitatively assess the possible benefits[6] provided by transmission expansion: this task, especially in a liberalized power system, generally represents a rather complex stage as the evaluation strongly depends on the viewpoint taken for each considered benefit. Manifold aspects in which a new infrastructure can affect the system have to be considered. These benefits can be grouped into several categories:

- system reliability increase,
- quality and security increase,
- system losses reduction,
- market benefits,
- avoidance/postponement of investments,
- more efficient reserve management and frequency regulation,
- environmental sustainability benefits,
- improved coordination of transmission and distribution grids.

However, only some of these items are quantitatively significant and can be measured by means of single indicators.
An evaluation of the economic impact of reliability increase can be carried out by multiplying the EENS value (Expected Energy Not Supplied), by an estimation of the VOLL (Value Of Lost Load).
The market benefits provided by transmission expansion can be summarized by two concomitant effects: the decrease of potential for exercising market power by dominant players (strategic effect) and the replacement of local inefficient generation by cheaper imported power due to the removal of existing transmission bottlenecks (substitution effect). Both effects can be measured by the Social Welfare parameter (SW)[7]. When planning the utilisation of fast power flow controllers such as FACTS and HVDC devices, an additional benefit could arise from the power flows controllability increase enabled by these technologies. However, this effect translates again into a substitution effect and, therefore, does not constitute a separate benefit from one measured by SW.
The environmental sustainability benefits by transmission expansion include: a better exploitation of a diversified generation mix (including RES generation), CO_2, NO_x, SO_2 emissions savings and reduction of conventional generation external costs (externalities), reduction of fossil fuel consumption and costs. Transmission upgrades may bring some additional environmental benefits in terms of land use reduction, visual impact abatement and decrease of the electromagnetic field (EMF).

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[6] It is crucial that the different benefits are not overlapping so as to avoid double-counting when they are summed up.
[7] SW is defined as the sum of generators and consumers surplus, see also [12].

Other benefits, which in the future may gain higher consideration, relate to the improved interaction of transmission and distribution grids within systems either experiencing high shares of distributed generation resources or even evolving towards SmartGrids schemes with a considerable deployment of distributed generation. A transmission investment may prevent much more expensive reinforcements of the distribution networks. However, this benefit is very difficult to translate into the measurement of a specific indicator, since it implies a complex and manifold process.

4.3.3 Transmission infrastructure costs

Capital investments for transmission system assets depend on different parameters, such as equipment type, rating and operating voltage, technology maturity, local environmental constraints, population density and geographical features of the installation area as well as costs of material, manpower and right-of-way. Local environmental constraints usually increase costs and implementation time - e.g. for Overhead lines (OHL) - while technological advances in manufacturing usually reduce costs: this is the case for power electronics components or for underground XLPE (Cross-Linked Polyethylene Extruded) cables. Moreover, equipment prices continuously change due to a dynamic world market: costs of European transmission assets are then influenced and driven by external factors. Taking all these factors into account, in [13]-[15] up-to-date (average) ranges for the costs of different transmission components in Europe are reported and compared.

As explained in [13]-[15], the lower limit (min value) of cost ranges refers to installation costs in continental European countries with low labour costs, while the upper limit (max value) of cost ranges refers to installation costs in continental European countries with high labour costs. Costs for OHLs are referred to the base case of installations over flat land and in sparsely populated areas. Costs for installations over hilly and averagely populated land as well as over mountains or densely populated areas can be calculated by a surcharge of +20% and +50%, respectively [13].

In the case of underground cables and GILs (Gas Insulated Lines), the cost component related to the installation expenditure can very much influence the final investment cost, depending on installation location, type of terrain and other local conditions [15].

The cost ranges provided for HVDC converter equipment are presented “per terminal”, wherein a terminal includes all equipment at one side of the bipolar transmission line: both converters, reactive compensation (if needed), active filtering, AC/DC switchgear, engineering, project planning, taxes etc. except any costs related to the transmission medium. In fact, it has to be noted that, on the one hand, Voltage Source Converter (VSC)-HVDC is by nature bipolar; on the other hand, bipolar HVDC installations are preferred within a synchronized power grid for system security reasons [13].

4.3.4 The tool REMARK

The evaluation of the benefits provided by a new infrastructure with respect to the status quo has to be performed by a tool able to assess the improvement of each benefit in the case “with” the new infrastructure respect to the case “without” it. This tool has to consider the real network situation in which the variability of RES generation as well as the reliability of each element in the grid are both accounted for. Additionally, the case to be considered has to be based on a “projection” to the future of the system, able to account for its evolution and its most severe criticalities.

With this aim, for REALISEGRID RSE has developed a new tool, REMARK [17], to conduct analysis of static reliability of complex electric systems that operate in a liberalized market context and are divided in areas. This might then be a situation typical of European regional markets. In comparison to conventional planning tools, the new tool quantifies both indices generally used to assess reliability of electric systems and indices aimed at innovatively assessing from the economic point of view the effects and the eventual criticalities caused by the market structure on the transmission system evolution.

Main features of this tool [12][17] are:

- full network representation adopting the simplified direct current model;
- an Optimal Power Flow (OPF) algorithm;
- probabilistic simulation of one year of operation of the power system using a non-sequential Montecarlo method starting by the reliability characteristics of the system components (components of both the transmission system and the generation set);
- probabilistic definition of the characteristics of variable wind generation, that is treated by the Montecarlo methodology as well;
- quantitative assessment of the reliability and economic benefits (both substitution and strategic effect), as well as other types of benefits (security of supply, environmental, etc).

4.3.5 Test-bed application in the European system

The methodology proposed and tested co-evaluates capital and operational costs of new infrastructures together with a wide range of benefits [27].

The benefits considered for the methodology application are:

- increase of social welfare (SW);
- reduction of losses;
- reduction of load shedding;
- reduction of wind curtailment;
- reduction of CO_2 emissions;
- reduction of the amount of money spent to import fuel from extra-EU countries.

A real sized test case has been set up and run in order to validate the cost-benefit methodology on a multi-national level. The considered list of expansion candidates is the one included in the Trans-European Energy Networks (TEN-E) priority axis “EL2 - Borders of Italy with France, Austria, Slovenia and Switzerland” (see Fig 7). The EL2 priority projects of European interest have been aggregated according to three main corridors: Corridor A (Germany-Austria-Italy through Veneto region); Corridor B (Slovenia-Italy); Corridor C (Germany-Austria-Italy through Brennertunnel).

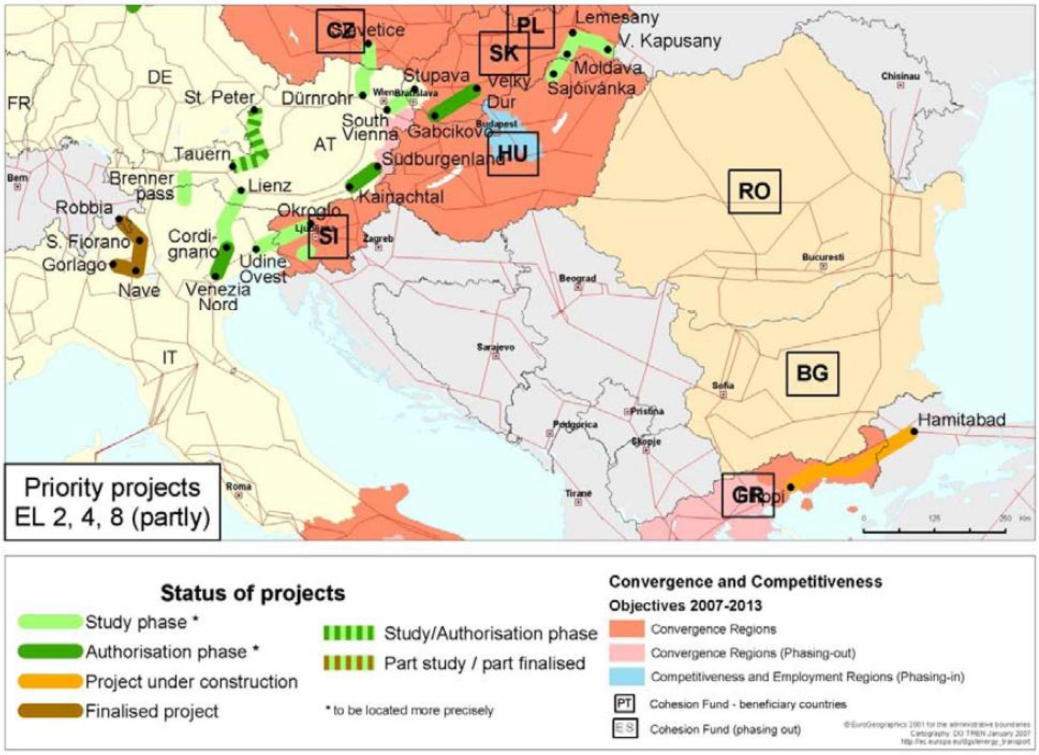

Fig 7 – The TEN-E EL2 Priority Projects of European interest (update: 2006) (source: [1])

The impact of the EL2 projects has been investigated in the "tab" years 2015, 2020 and 2030. For each of these reference years, different system models that describe the evolution scenarios of generation, loads and transmission grid have been prepared. The dimension of the test-bed is very wide, covering a large part of the continental European system of ENTSO-E (European Network of Transmission System Operators for Electricity). In fact, it includes the bulk power system of France, Germany, Switzerland, Austria, Italy, Slovenia, Croatia, Bosnia-Herzegovina, Serbia, Montenegro.

The network model used as a reference for the simulation is based on the continental Europe STUM (Study Model) provided by the ENTSO-E (2008 winter peak). The necessary information and data required to update the 2008 model to the reference years (2015, 2020, 2030) have been taken from the ENTSO-E's Ten-Year Network Development Plan (TYNDP) 2010-2020 and from public sources (also to include merchant transmission projects). Further information and data have been provided by the REALISEGRID TSOs and partners as well.

Generation park and demand data have been set up according to two scenarios (optimistic and pessimistic), whose trends have been based on the ENTSO-E's System Adequacy Forecast and the long term scenarios developed within REALISEGRID.

Based on the relevant simulation scenarios developed, the cost-benefit analysis applications have been performed in the cases "with" and "without" the new investigated infrastructure [27].

The analysis of the results shows first that the benefits are generally able to recover the costs after few years of operation. Furthermore, from the results it emerges that the SW benefit (B1) is the prevailing one, but fuel import reduction (B6) is very impacting too. For this reason a sensitivity analysis related to the impact of B6 has been also carried out.

In general, as expected, the expansion of the interconnections on the corridor Germany-Austria-Italy produces a decrease of the total dispatching costs as well as the reduction of the price differential between the related markets.

The results concerning the effect of emissions indicate that, unless specific regulatory provisions are taken, the CO_2 emissions can grow. In fact, the Italian gas generation is in general mostly replaced by less expensive German coal generation whereas the North Sea RES production, due to internal bottlenecks in Germany but also to the relative inadequacy and lower capacity factor of wind power, is mostly limited to German consumption. This is particularly evident in short and mid term horizons (up to 2020) and for the pessimistic case also in the long term (2030), when nuclear power capacity, according to the simulation scenarios, is supposed to be completely phased-out in Germany.

In many cases, the results show that grid losses are generally increased by inserting new corridors. This effect could be explained by considering that the new corridors let the global power exchanges in the network increase and, therefore, the losses (that depend on the power flows) can also rise.

The effects of some other benefits, like the increase of system reliability and the reduction of wind curtailment, play in all cases a very limited role. In fact, the investigated portion of the European transmission network has proven to be sufficiently reliable over the observed timeframe. In addition, the grid expansion over the years, within the timeline and geographic coverage of the study, has resulted to be able to efficiently integrate the expected growth of wind power capacity.

From the analysis of the results, by comparing the three alternative corridors, it can be noted that:

- In the optimistic scenario, Corridor C results to be the most profitable solution, preceding in the rank Corridor A and Corridor B (in both cases with and without B6), when taking the NPV (Net Present Value) as the evaluation indicator for the decision-making. On the other hand, by selecting the investment based on a relative indicator like the PI (Profitability Index), the rank order changes, seeing Corridor A as the most convenient option followed by Corridor B and Corridor C (in both cases with and without B6). This rank change can be explained by the high amount of investment needed for building Corridor C.
- In the pessimistic scenario, in the case with B6 included, the order rank of investments is the same as for the optimistic scenario, i.e. Corridor C is the most convenient option, followed by Corridor A and Corridor B, when taking NPV as decision-making indicator, while Corridor A can be preferred over Corridor B and Corridor C considering the PI as indicator. Instead, in the case without B6, Corridor A results the most convenient by using both indicators to base the decision, followed by Corridor C and Corridor B or reversely, depending on the indicator adopted (NPV or PI, respectively).

It has to be added that in both scenarios, the Corridor B option is ranked lower due to internal congestions not solved within the Balkan area region (in spite of the new interconnectors).

In general, notwithstanding some data uncertainties concerning the network system and the generation set, that may affect the final conclusions on grid investments ranking, the real advance brought by the test case is to show the applicability of the theoretical framework of the multi-criteria cost-benefit analysis elaborated by REALISEGRID to a realistic case encompassing a significant range of European nations.

Due to its neutral and general theoretical features, the proposed REALISEGRID framework might be further applied for a future pan-European methodological approach to the expansion of the European backbones, as called for by the already quoted 2010 Energy Infrastructure Package of the European Commission [27].

Finally, two other fields can be mentioned in which, in the view of the REALISEGRID project, the cost-benefit analysis methodology outlined in the present report might be helpful:

- The transmission investment profitability assessment could serve to set up a possible Key Performance Indicator (KPI) to be added to a basis Return On Investment (ROI) parameter towards the final remuneration of the TSOs for their investments in new infrastructure. This addendum could stimulate the TSOs themselves to adopt an optimal investment policy for the system, notwithstanding the different difficulties connected with the authorization process of specific infrastructures. Such a cost-benefit evaluation could, indeed, be measured on the field after the new infrastructure is put in service, but this would require a significant time shift due to the usually long time needed for authorizing and building new infrastructure(s). A very interesting alternative is to draw the same parameter from a possible future pan-European simulation model trusted by both the European Commission and ENTSO-E.

- An evaluation of transmission investments cost-benefit analysis could serve to provide the public with a fair information about the advantages deriving from new grid infrastructures as well as about the economic costs deriving from unneeded delays in the authorization procedure (the so-called inaction cost). This could also be useful to tackle the frequent dissent attitude manifested by the public opinion toward new infrastructures.

4.4 WP3.4 - Coordinated assessment of electricity and gas grid investments

The growing installation and utilization of natural gas fired power plants (NGFPPs) over the last two decades has led to increasing interactions between electricity (E) and natural gas (NG) sectors. NGFPPs are the link between electric power and NG systems, since they play the role of producers for the former and consumers for the latter. Therefore, the growing use of NGFPPs has had a great impact on the NG market. There is a strong and rising interdependency between natural gas and electricity sectors and it could be useful to include NG system models in electric power systems operation and planning. On the other hand, NG system operation and planning require, as input data, the NG demands of NGFPPs, whose values can only be obtained accurately from the electric power systems dispatch.

The approach to assess the investment in NG&E transmission infrastructure has the following characteristics:

- The analysis is focused on proposed or possible transmission expansion projects, thus the capacity of these expansion projects is not a variable within the optimization procedure.
- The performance or benefits of the transmission expansion projects are evaluated by means of their contributions to reduce the NG&E production and shortage costs. The installation or construction of new transmission infrastructures ease the transmission capacity constraints, therefore, in general, the production costs decrease (or shortage costs are avoided) because the transmission network imposes fewer limitations on the production dispatch. Other possible benefits arising from additional transmission assets are not considered in the proposed approach.
- The demands for electricity and NG not used for electric power generation are modeled as totally inelastic, thus the maximization of social welfare is equivalent to a minimization of the NG&E production and shortage costs. In this context, the cost savings, associated with each transmission expansion project, are calculated using the *with/without analysis.*
- The transmission expansion problem is formulated as a *static* problem since the timing of the commissioning of the new transmission infrastructure is not a decision variable. It is considered that the expansion projects are installed at the beginning of the assessment period. However, the evaluation takes into account a multi-period analysis with a 20 year investment time horizon (until 2030).
- Some relevant random uncertainties, such as NG&E demands, fuel costs and wind power production, are considered in the proposed *probabilistic* approach. A Monte Carlo simulation is used to calculate the probability distribution functions of the cost savings due to the installation of the different transmission expansion projects.

- A probabilistic net present value (NPV) for each transmission expansion project is calculated to rank the expansion alternatives. Each probabilistic distribution of the NPV is calculated through the convolution of the probability distribution of the cost saving at years 2010, 2015, 2020, 2025 and 2030, and considering that the total investment cost is spent at year 2010 (beginning of the assessment period). The expected value of the NPV, a risk neutral metric, is used to build the expansion alternatives' ranking.

The core of the proposed approach is a NG&E operational planning model which is used as the main tool to assess the cost savings due to the investments in NG&E transmission infrastructure. This model is essentially a multi-period optimal NG&E flows subject to time coupling constraints. The main characteristics of this model are:

- The coordination of NG&E operations is addressed using a combined approach, i.e., a single optimization problem integrating the models of the natural gas and electricity systems.
- The time horizon considered in the NG&E operational planning covers a whole year to deal properly with the seasonal behavior of NG&E demands and some energy resources such as water inflows and wind power production. This one year time horizon, usually classified as medium-term time horizon, also allows us to model the energy storages adequately and, thus, to include their scheduling in the optimization problem. This is important since transmission and storage facilities are complementary, and therefore, the cost savings due to a transmission expansion are affected by the storages capacities.
- Mathematical programming algorithms are implemented to solve the optimization problem.
- The medium-term NG&E operational model is used within the Monte Carlo simulation method to assess the impact of the considered random uncertainties on the cost savings.

Using the medium-term NG&E operational planning model within a Monte Carlo simulation process, it is possible to obtain the probability distribution of the cost saving due to the investments in NG&E transmission infrastructure for a certain year. Thus, the probabilistic NPV for each transmission expansion project is calculated by means of the convolution of the probability distribution of the cost saving at years 2010, 2015, 2020, 2025 and 2030, and considering that the total investment cost is spent at year 2010. The ranking of the expansion alternatives is based on the expected value of the NPV for each one of the considered alternatives [25].

The described approach has been applied at EU36 level and the application results have been reported in [26].

5 MAIN FINDINGS ON TRANSMISSION REGULATION

The present Chapter provides the main findings of the REALISEGRID WP3 works on the regulatory aspects related to transmission expansion planning in Europe. These include: the remuneration and incentivisation of transmission investments; the authorisation procedures and the consensus issues. Finally, policy recommendations are drawn.

5.1 WP3.6 - Transmission investment regulation and incentivisation

The progressive opening of electricity markets in Europe entails a redefinition of several parameters regarding incentive regulation, regulatory governance and market design assessment, in order to achieve the liberalization targets. New investments in cross-border electricity networks have emerged as a crucial need to better integrate the Internal Electricity Market (IEM), secure the electricity supply and facilitate the integration of renewable energy sources (RES) into the European grid. This is a process involving various stakeholders as TSOs, national regulators and European institutions, with the aim to harmonize national needs with the pan-European interest.

This activity has investigated the regulatory framework of the European TSOs remuneration policy with particular attention to the incentives schemes for developing transmission networks in the European electricity sector, and specifically cross-border interconnections.

This activity has focused firstly on the regulatory context related to transmission incentive mechanisms that could stimulate the implementation of TSO's network investments, by presenting the main approaches used worldwide for regulating transmission network development which span from the traditional cost-plus model to the more performance-based schemes, as the "cap-regulation". A complement to the regulated transmission investment model is also explored by presenting the merchant transmission investment scheme, based on a private investment approach, where parties concerned are fully or partially exempted from the rules on third party access and/or the rules on the use of the congestion rents. However, this option remains a relatively minor issue in Europe. Projects having recently granted exemptions have to observe a stringent set of conditions concerning the impact of the project on competition, not forgetting network externalities and the risk to hamper regulated investments which remain the rule.

Despite there are both positive and negative aspects concerning interconnections investments at technical, economic, environmental and socio-political level, there is a common agreement on the advisability of optimizing regulation on investment incentives in Europe. TSOs, who are usually the main agent tasked with identifying and delivering additional transmission infrastructure, might not have sufficient incentives to fully consider the potential for investing in transmission capacity improvement, and while the need for substantial investment in more electrical interconnection capacity is widely recognized, the ways and means to promote such investments are more controversial. Potential interconnector investors are further discouraged by the existence of a "regulatory gap", due to the fact that each regulator only has authority within its national market and no authority decides on cross-border and regional issues. There is no supra-national authority responsible for the cost allocation of cross-border projects - for example deciding on a compensation for transit country - and investors face an important risk of project failure when the concerned national regulatory authorities are unable to agree on key cross-border regulatory provisions. Moreover, a lack of supra-national network planning may impede the identification of the most beneficial interconnector investments.

By comparing theory and current praxis, one of the main worries emerged is a lack of explicit incentivization for new efficient investments. Incentives are mostly set for short-term projects, and that represents a main concern especially in the case of long-term and lumpy investments, as cross-border networks are. In the view of the REALISEGRID project, a thorough cost-benefit analysis should be the correct foundation for a correct evaluation of investment efficiency, on the basis of which an increase in the return of investments of the TSO could be calculated. Meanwhile, the Inter-TSOs compensation (ITC) mechanism, still too weak and not truly cost-reflective, should be reformed: an extension of the current scheme covering also investment costs could be the right solution to allow motivating the so-called "transited countries", i.e. those which contain neither the source nor the destination of the electricity transactions. An adequate harmonization of national revenue and incentivization schemes should emerge too, integrated with the new ITC-mechanism, in order to avoid distortion of the economic signals.

Cost-benefit analysis and new ITC-mechanism should be combined with a proactive behavior of the TSOs in their investment activity. The liberalization process, implying the separation between generation and transmission, caused an asymmetry of the investments coordination which generates bottlenecks and delays, particularly in an uncertain regulatory environment. Taking into account investors' interest for generation technologies with short lead construction time, the proactive behavior of the TSOs could facilitate the connection of these types of power plant and encourage market entry. The anticipation of the planning of some specific network investments, as the cross-border ones, avoids that congestion appears, with negative consequences on dispatching costs, while the new power plants are still in the building phase and new power lines are still in their administrative phase.

Finally, a kind of innovative approach is suggested as an example of a second best option for fostering cross-border investments. This alternative financing mechanism constitutes a hybrid model where the regulated framework is kept, with some integration permitting to involve private funds which may constitute a good opportunity in order to accelerate the investment process.

The following points summarize the central outcomes and the main recommendations:

- National TSOs are regulated subjects and define their objectives in relationship to the regulation and the remuneration schemes (rate-of-return, cap regulation…). Regulation, necessarily imperfect, is reflected into a possible non-optimality of the investment policies. Thus, the central point is how to promote efficiency.
- Efficiency could be measured ex post after the investment becomes operative (big delays and meanwhile the market has changed!). An ex-ante index derived from the cost-benefit analysis could constitute a new KPI in percentage to which an increase in the return of investments of the TSO could be calculated.
- Trans-national investments: interested TSOs draw a different incentivization. How to motivate "crossed" countries? An extension of the current ITC mechanism covering also investment costs could be the solution provided that a more price reflective scheme is implemented.
- Exporting countries see prices grow. The regulation should provide mechanisms able to transfer to the population part of the extra gain of the generators.
- Merchant investments are generally seen as non optimal (violation of third party access and/or need for the congestion to remain). There exists an interesting alternative: energy-consuming customers financially could profitably support the investment of the TSO in exchange of a reduction of the obligations concerning possible interruptions they are subject to.

5.2 WP3.7 - Transmission expansion issues: authorisation procedures and consensus

Generally speaking, approval procedures for building new transmission lines cover the following stages: the TSO is the initiator of the project and conducts first a feasibility study. The purpose of this study is to plan several route options for building a new transmission line. These options should be feasible in all aspects, namely technical, technical-economical, administrative, social and environmental. The planning authorities are involved in this process – formally or informally – with regard to spatial planning, environmental aspects etc. This study phase is concluded by requesting the respective authority to permit construction of the transmission infrastructure along one of the proposed routes that proves to be optimal. At the centre of this application is the environmental impact assessment (EIA), which has to be performed according to EU and national laws in all member states. In some countries a strategic environmental assessment (SEA) is also performed beforehand at national level for potential new infrastructures, but its results are not used in the EIA. With respect to national environmental legislation, local authorities will be involved. In addition, a public debate or a formal dialogue is compulsory and each stakeholder has a right to express his own opinion. Finally, all other national legal requirements (concerning water rights, protection of the right of property building law, environmental protection, conservation of protected species etc.) will have to be met. Only afterwards, will the approval be given by the authority in charge. For building a new line, licenses also have to be obtained, and this process is done after or simultaneously with the authorization procedures. The expropriation phase is effected in the end via either amicable agreements or legal easements. When all approvals are granted, the construction process can begin.

International projects follow the same steps described above, but these steps are done for each of the involved countries according to their own national procedures. It is important to decide first on a physical interconnection point at the border, before starting the rest of the procedures. If the authorization process takes longer in one country, the whole project will suffer.

Concerning specifically the priority projects of European interest, the REALISEGRID research project proposes to combine two synergic actions in order to streamline and facilitate the transmission planning process. In particular, this combination consists of:

- an efficient consensus process that also implies a good information flow from and to the population (bottom-up approach); the main targets are related to:
  - providing a clear vision of benefits and costs related to the new infrastructure. Clearly state the cost for the society deriving from inaction or sub-optimal actions.
  - promoting an educative action meeting all the points of view in the perception of a new line. Clarify the relationship between RES integration and grid development. Clarify the relationship between costs and different technical solutions (e.g. cabling, HVDC).
  - promoting a thorough evaluation of property value, so as to bring about a fair compensation value that can be agreed by all the parties.
- a clear regulatory approach (top-down approach), harmonized throughout Europe. The ground targets are related to:
  - acting on the legal framework: simplify, harmonize, set time limits and rationalize the procedure (number of entities, number of phases, etc.).
  - creating, especially for the most important projects, an "arbiter" (facilitator) to promote shared solutions and to manage the entire procedure in trans-national cases.

The basic targets of a clear and harmonized regulatory approach are related to two main aspects. On the one hand, it is important to act on the legal framework: simplify, harmonize, set time limits and rationalize the procedure (number of entities, number of phases etc.). Clear and harmonised authorization procedures are essential to obtaining a fast implementation of priority projects. On the other hand, facilitators should be appointed for national and EU priority projects, to promote shared solutions and manage the entire procedure in trans-national, but also national cases. Considering European priority projects, their urgency should suggest revising Europe-wide the entire approval mechanism by creating fast (priority) approval pathways at both national and local level.

A key element in the consensus process is a good information flow to all participants. They should be given beforehand both general information about how power systems work and what transmission planning involves, and also background information, such as the costs and benefits of the new transmission project, and any other important information relevant to the problem to be solved. The information flow has to consider all costs and benefits and clearly show the cost of inaction for all stakeholders. For facilitating this interaction, an approach for properly communicating the benefits of transmission projects and the cost of inaction is introduced.
In addition, it is important to have a thorough evaluation of property value, so as to bring about a fair compensation value that can be agreed by all parties. Compensation schemes have to be proportional both to the actual value of the caused damage and to the importance of the project and they should not foster free-riding strategies amongst stakeholders. The creation of a skilled and impartial body to act as project facilitator is generally recommended in such situations. He should be able to engage with all the participants and guide the process towards a supported solution, solving when necessary cases of minority dissent and isolating "continually antagonistic attitudes".

One should keep in mind that in order to reduce the opposition for a certain project, stakeholders have to be involved in the decision-making process. The public perception of new transmission lines should be considered, and conflict dynamics should be studied as they can change the ratio between the different factors that influence public attitude due to opportunity reasons. Consensus must be sought from early phases of the planning process and also during the authorization phase, and hence the public should be involved at all these stages. In complex infrastructure planning issues, it is very hard to get all the stakeholders to agree, and hence the need for compromise seeking usually arises. Nonetheless, the target should be increasing the public acceptance of a certain project. This can be done at several levels, namely international, national, regional and local. Three consensus processes were suggested between these levels: international-national, national-regional and regional-local.
Building a new a transmission line problem should be treated as an unstructured problem that needs a high public participation and also involvement of experts, all taking part in the action of problem structuring. Strategies on how to present the background information should be developed in order to emphasize the importance and all benefits that are brought by the new infrastructure. Compromise seeking Decision Aid Systems (DAS) for selecting a power line path could be used during the process. It would be useful if the TSOs were supported in their attempts of obtaining consensus by authorities such as the State, the Regions and Municipalities, users of the grid and other important bodies. For the authorisation phase a simple legal framework and acceleration of procedures is the first help needed from the authorities. Moreover, authorities should give public support and assume their responsibilities. The sensitivity to political instability/changes should be reduced if possible.

Concrete actions and timelines can be defined on different time horizons as illustrated in Tab 2.

Time Horizon	Actions
Short-mid term	Transparent and serious communication and information to the public
	Involvement of public in the decision-making from early stages of the planning process
	Utilisation of a neutral cost-benefit analysis
	Communication of inaction costs
	Creation of a skilled and neutral project facilitator
	Set up of a clear, fixed timeline for approval
	Utilisation of innovative transmission technologies
	Exploitation of existing transmission assets
	Development of European wide standards on EMF
	Fair compensation schemes
Mid-long term	Streamlining of authorisation processes
	Pan-European harmonisation of procedures
	Set up of clear incentive schemes
	Transmission planning anticipation with respect to generation planning
	Harmonisation of EU and national legislations
	Implementation of market reforms
	Definition of a merchant investment framework

Tab 2 - Speeding up procedures: concrete actions and time horizons

The short- to mid-term actions can be developed without touching the roles and general principles established by national and European regulations. On the mid- to long-term, actions have to be focused on a general harmonization process that requires revising, at least partially, of the roles and/or the general principles adopted in the national and European regulation (e.g. the principle of subsidiarity).

Last, but not least, it should be kept in mind that each project is different and actions should be tuned based on specific particularities for each situation.

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